# Space Weather Technical Forecast

Issued on Saturday, 16 December 2023 at 00:37 Local

**This technical forecast provides a four day assessment of space weather events. The probabilities stated below are for reaching or exceeding the given levels. For more information about space weather impacts please see the Met Office Space Weather Scales https://www.metoffice.gov.uk/weather/learn-about/space-weather/uk-scales**

**Space Weather Forecast Headline: M-flares likely, and chance of X-flares (R1-R3). G1-G2/Minor-Moderate Storms possible Days 1 and 2 (16-17 Dec) with CME arrivals, slight chance of G3/Strong Storms. S1/Minor Radiation Storm in progress, risk reducing later in the period. Chance of Active fluence by Day 4 (19 Dec).**

**Analysis of Space Weather Activity over past 24 hours**
**Solar Activity:** Moderate with a double peak flare, reaching M6.9 from AR3514 in the northwest disc, peaking at 15/0734 UTC. This was the region also responsible for an X-flare on the 14 Dec. There are now ten sunspot regions, with the most significant being AR3514. This region does look as though it is decaying slightly, probably losing its delta spot, although it is becoming difficult to tell as it continues to rotate towards the western limb. SDO imagery continues to show magnetic looping across the region. AR3519 has grown recently, but is not significantly magnetically complex. The other regions remain much smaller and simpler, although a couple of new regions are appearing near the east limb and may be more complex than can currently be seen.
Two CMEs were observed in the last 24 hours with a potential Earth-directed component. One from the M6.9 double-peak flare produced by AR3514, but this is now considered most likely to miss ahead of Earth. We are awaiting imagery after a recent filament eruption near south centre disc to see if this has produced a CME.

**Solar Wind / Geomagnetic Activity:** Solar winds, as measured by ACE and DSCOVR at L1, showed a weak CME arrival at 15/1057 UTC. Wind speeds were initially at background levels, around 300 km/s, but jumped after the CME arrived and varied between 370-500 km/s. Density was below average at first, but became above average after the CME arrived with a peak of 40ppcc. The interplanetary magnetic field, Bt, was weak around 5nT, becoming moderate to strong after the CME arrived with a peak of 23nT. The north-south component, Bz, was weakly negative (southward), then varied mostly moderately after the CME arrival between +17/-13nT. Phi angle was largely neutral at first, becoming more positive (away from the Sun). Geomagnetic activity was Quiet to Unsettled (Kp 0-3).

**Energetic Particles / Solar Radiation:** GOES16 high energy (greater than 10MeV) proton flux gradually rose above the S1/Minor Radiation Storm level, peaking at 13 pfu. This was in response to the recent larger flares from AR3514. GOES16 high energy (greater than 2MeV) electron flux was mostly at background levels, with a brief moderate peak. The 24-hour fluence was well below the Active threshold (1e8 integrated pfu) on a slight rising trend. The observation at 16/0000UTC was 4.03e6 integrated pfu.

**Four-Day Space Weather Forecast Summary**
**Solar Activity:** Moderate to High activity expected with the ongoing likelihood of M-class (R1-R2) flares and a chance of further isolated X-class (R3) flares from AR3514. This risk recedes later Day 2 and through Day 3 (17-18 Dec) as the region rotates off the disc.

**Solar Wind / Geomagnetic Activity:** There are a number of possible Earth-directed CMEs. The

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first is expected to arrive early Day 1 (16 Dec), but any impact is likely to be limited due to the faint nature of the CME. The X2.8 flare from AR3514 produced a moderately fast CME which is likely to have an Earth-directed component, most probably arriving early on Day 2 (17 Dec). However confidence in this analysis is rather low. A further weak CME early on 14 Dec looks to be cannibalised by the X-flare CME. It is possible that there is some weak fast wind influence from CH79/+ at present, but largely masked by the current CME arrival. CH82/+ may then enhance the solar wind speed to elevated levels on Day 3 or more likely Day 4 (18-19 Dec). Geomagnetic activity is expected to be Unsettled at first, possibly rising to give spells of Active to G1/Minor Storm early on Day 1 with the first forecast CME arrival. The second CME arrival is likely to give G1-G2 Minor to Moderate storms early Day 2, with a slight chance of isolated G3/Strong storm intervals. A return to mainly Quiet to Unsettled conditions is likely during Day 3 (18 Dec), perhaps increasing again to Unsettled to Active with any fast wind enhancement from CH82/+.

**Energetic Particles / Solar Radiation:** GOES16 high energy proton flux is now just above the S1/Minor Radiation Storm threshold, with a chance of reaching the S2/Moderate level should there be further significant flares from AR3514. The risk of Radiation Storms gradually reduces later in the period as AR3514 rotates off the disc. High energy electron flux, as observed by GOES16, is currently at background levels. The forecast CME arrivals are likely to keep flux levels suppressed until Days 3-4 (18-19 Dec), when an increase is possible. The associated 24 hr electron fluence may start to rise Days 3-4, with a chance of exceeding the Active threshold.

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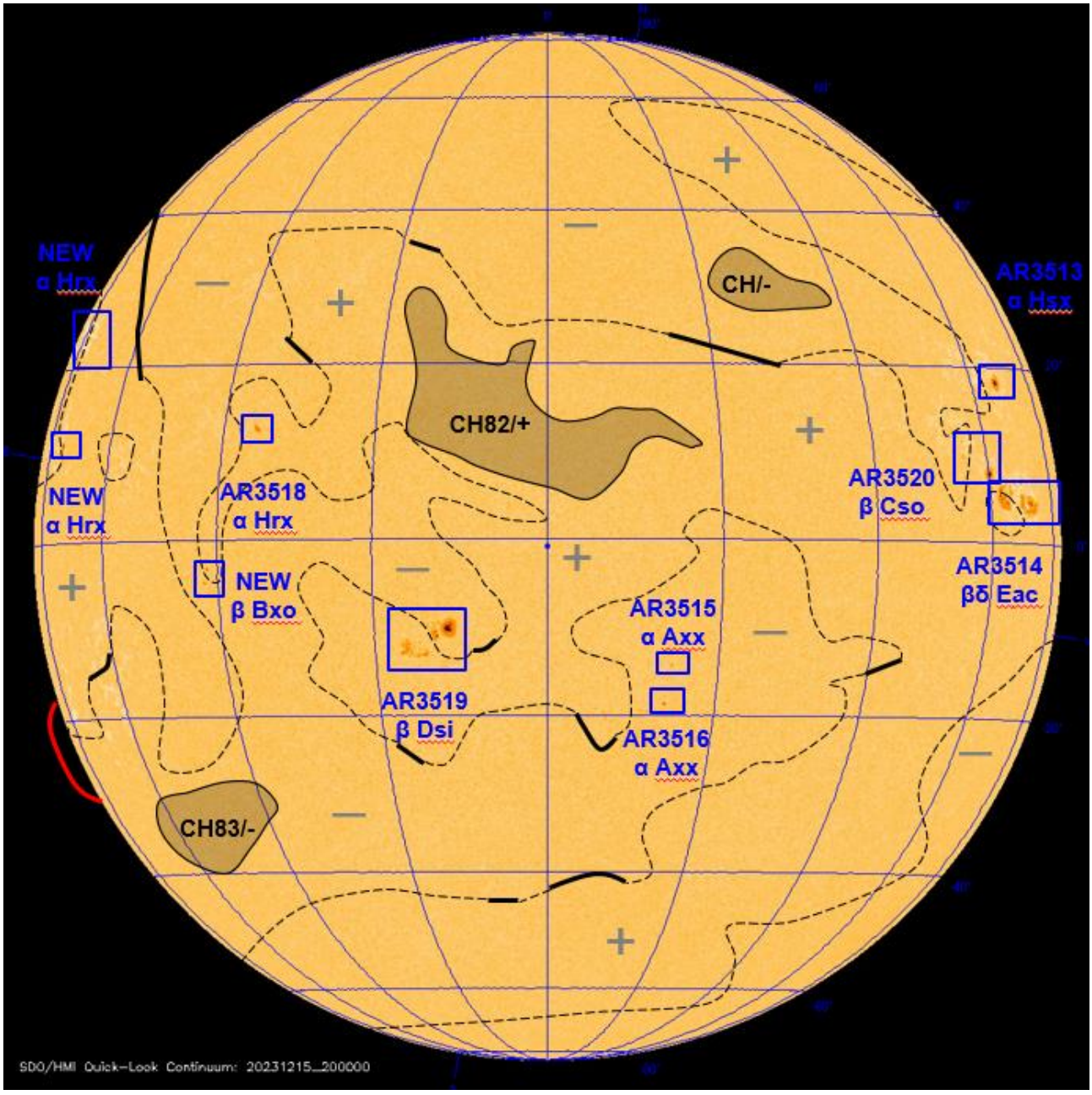
**Figure 1. Solar Analysis Valid 15/2000 UTC.**




**Key:** Filament ___ , Prominence ___ , Magnetic Field Line - - - , Polarity +/-, Coronal Holes: Grey shaded area CHxx +/-, Sunspot groups 25xx - Mt Wilson α-β-βγ-βγδ and Zurich-McIntosh Axx etc.

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## Geomagnetic Storms:

A CME arrived at L1 at 15/1057 UTC. It is uncertain as to the origin of this CME, but it could either be an un-forecast CME, or potentially an early arrival of one of the forecast CMEs mentioned below, which reduces confidence in the forecast somewhat.

There are a number of possible Earth-directed CMEs. One is from a filament eruption near AR3514 on 13 Dec and is expected to arrive early Day 1 (16 Dec). Any impact is likely to be limited due to the faint nature of the CME. The X2.8 flare from AR3514 at 14/1702 UTC produced a moderately fast CME which is likely to have an Earth-directed component, most probably arriving early on Day 2 (17 Dec). However confidence in this analysis is rather low. A further weak CME was observed early on 14 Dec. This was from a filament eruption off the north disc starting around 14/1109 UTC. This has been assessed, and looks to be cannibalised by the X-flare CME.

An enhancement was considered possible due to the fast wind from CH79/+, however this feature has been closing up as it crosses the visible disc. It is possible that there is some weak fast wind influence at present, but largely masked by the current CME arrival. CH82/+ may then enhance the solar wind on Day 3 or more likely Day 4 (18-19 Dec), with this feature giving an increase in wind speeds to elevated levels on the equivalent of Day 4 on the previous rotation. Geomagnetic response to coronal holes tends to be muted at this time of year, however. Geomagnetic activity is expected to be Quiet to Unsettled at first, possibly rising to give spells of Active to G1/Minor Storm early on Day 1 with the first forecast CME arrival. The second CME arrival is likely to give G1-G2 Minor to Moderate storms early Day 2, with a slight chance of isolated G3/Strong storm intervals. A return to mainly Quiet to Unsettled conditions is likely during Day 3 (18 Dec), perhaps increasing again to Unsettled to Active with any fast wind enhancement from CH82/+.

| Geo-Magnetic Storm Probability (Exceedance) | Level | Past 24 Hours (Yes/No) | Day 1 (00-24 UTC) (%) | Day 2 (00-24 UTC) (%) | Day 3 (00-24 UTC) (%) | Day 4 (00-24 UTC) (%) |
|---|---|---|---|---|---|---|
| Minor or Moderate | G1 to G2 | No | 50 | 60 | 20 | 5 |
| Strong | G3 | No | 15 | 20 | 2 | 1 |
| Severe | G4 | No | 2 | 5 | 1 | 1 |
| Extreme | G5 | No | 1 | 1 | 1 | 1 |

## Geomagnetic Activity - Earthbound Coronal Mass Ejections

| Date/time 21.5R (UTC) | Halo: Full or Partial | Source | Source Location | Estimated Speed | Estimated Arrival Time | Comments |
|---|---|---|---|---|---|---|
| 13/0555 | Partial | Filament nr AR3514 | NW | 530 km/s | Early 16 Dec | Low confidence |
| 14/2112 | Full | X2.8 from AR3514 | NW | 974 km/s | Early 17 Dec | Low confidence in timings. |

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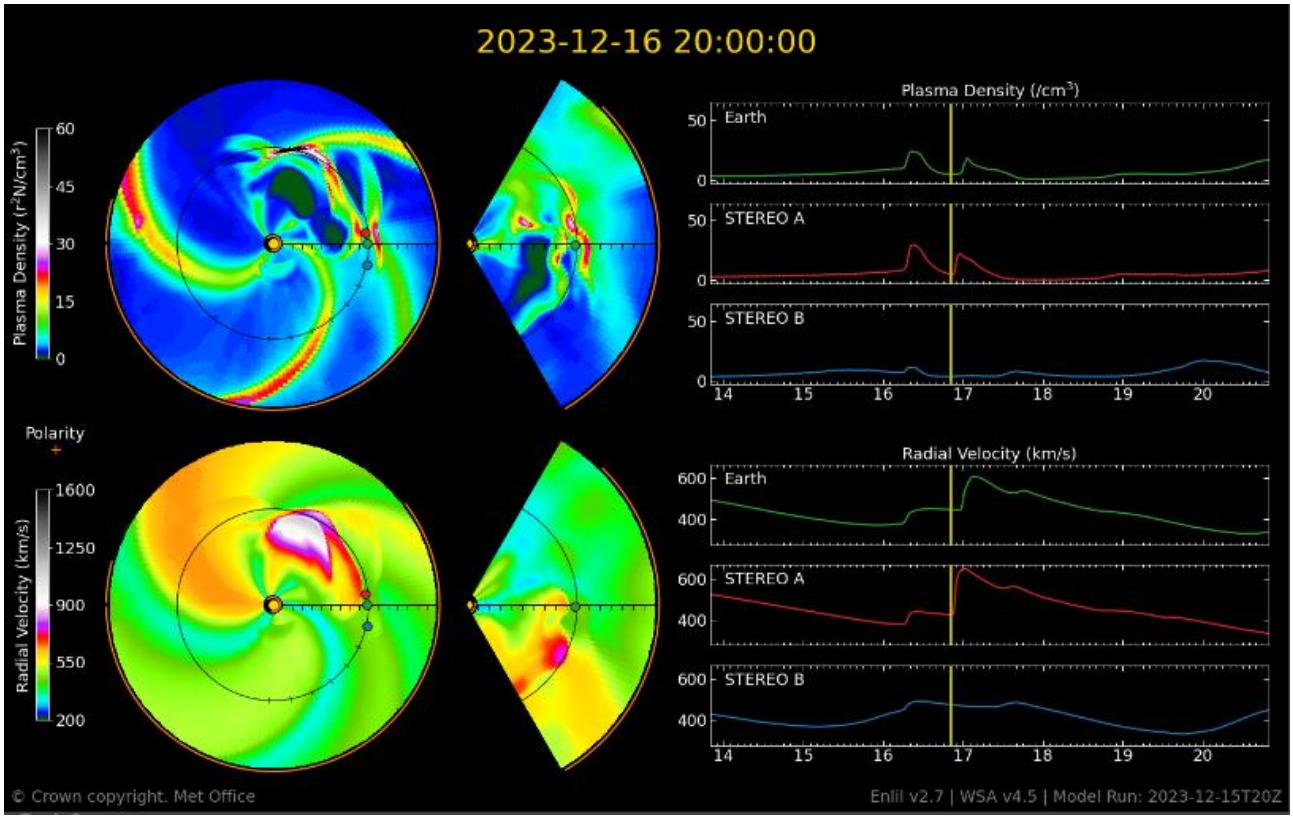
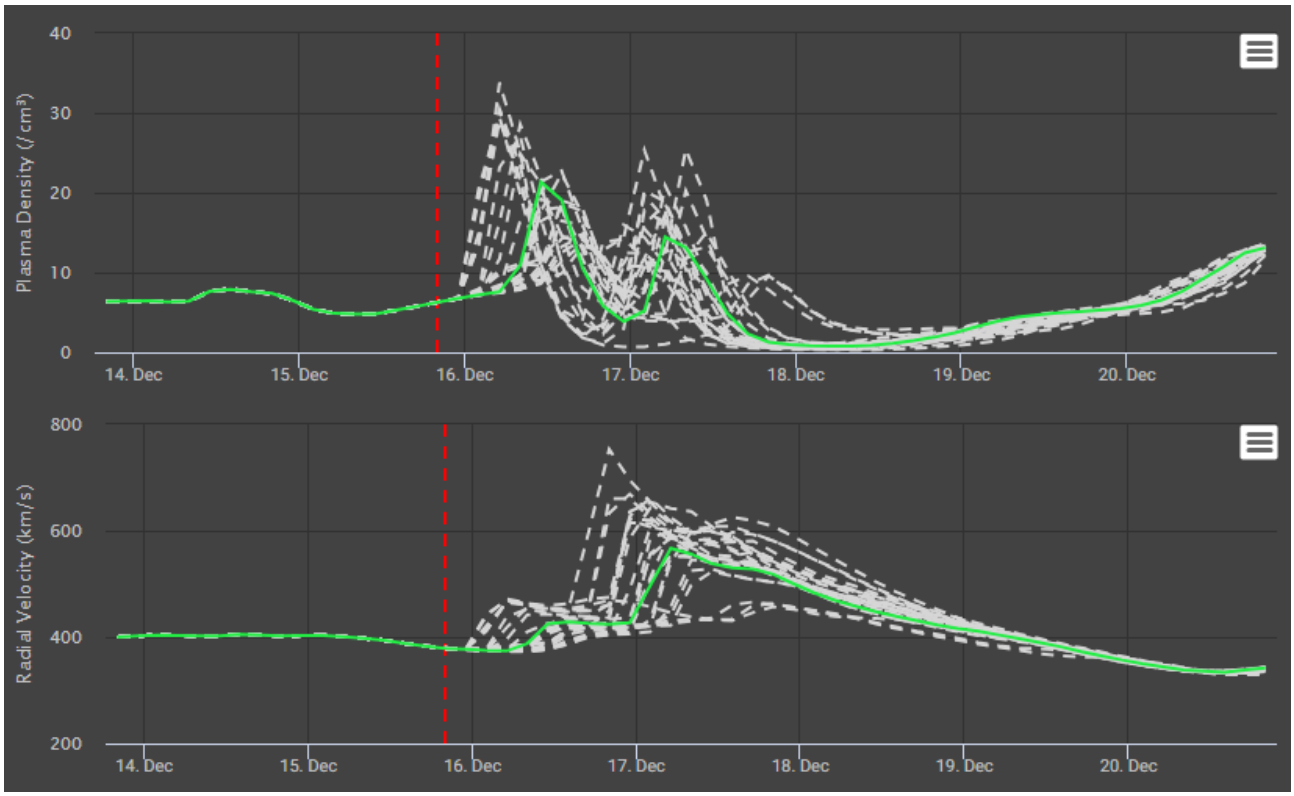
**Figure 2: MOSWOC Enlil and ensemble, showing two main CME arrivals – one early on 16 Dec and the next early on 17 Dec.**

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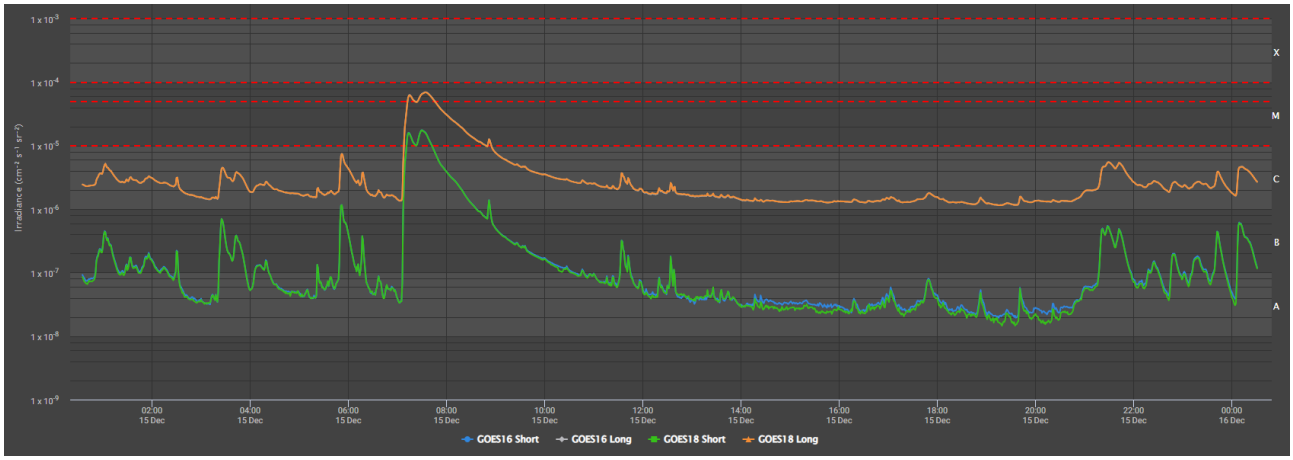
**Radio Blackouts - X-Ray Flares:**
Moderate to High activity is forecast, with the ongoing likelihood of M-class (R1-R2) flares and a chance of further X-class (R3) flares from AR3514. This activity is expected to decline as AR3514 rotates off the disc during Day 2 (17 Dec).

There are now ten sunspot regions, with the most significant being AR3514 in the west. This region does look as though it is decaying slightly, probably losing its delta spot, although it is becoming difficult to tell as it continues to rotate towards the western limb. SDO imagery continues to show strong magnetic looping across the region. AR3519 has grown recently, but is not significantly magnetically complex. The other regions remain much smaller and simpler. However a couple of new regions are appearing near the east limb, again with clear magnetic looping in SDO imagery, so these regions may be more complex than can currently be seen.

| X Ray Flares | Level | Past 24 Hours (Yes/No) | Day 1 (00-24 UTC) | Day 2 (00-24 UTC) | Day 3 (00-24 UTC) | Day 4 (00-24 UTC) |
|---|---|---|---|---|---|---|
| Probability | | | (%) | (%) | (%) | (%) |
| Active | R1-R2 M Class | Yes | 60 | 60 | 50 | 40 |
| Very Active | R3 to R5 X Class | No | 25 | 25 | 10 | 5 |

**Figure 3: X-ray trace from GOES16 and 18, showing Moderate activity in the last 24 hours from AR3514.**

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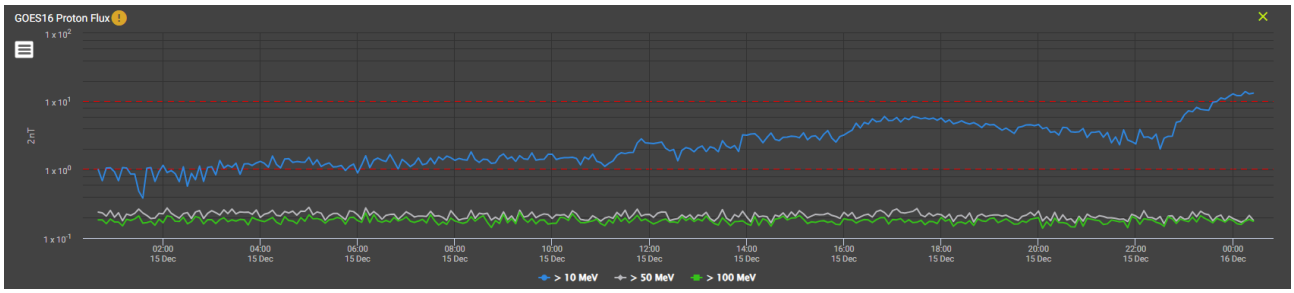
**Solar Radiation Storms - (High Energy Protons):**
The high energy (greater than 10MeV) proton flux observed by GOES16 has gradually risen after the X2.8 flare and subsequent flares from AR3514, and has just gone above the S1/Minor Radiation Storm level. The flux is likely to remain above the S1 threshold on Day 1 (16 Dec), with any additional significant flares from AR3514 meaning that there is a chance of further increases above the S2/Moderate level. In the absence of further flares, proton flux will probably slowly decline through the coming days. AR3514 will rotate off the disc during Day 2 (17 Dec), but any far-side flares on Day 3 (18 Dec) will continue to give a risk of high energy protons, before this risk declines during Day 4 (19 Dec).

| Radiation Storms Probability (Exceedance) | Level ($cm^{-2}$ $sr^{-1}$ $s^{-1}$) | Past 24 Hours (Yes/No) | Day 1 (00-24 UTC) (%) | Day 2 (00-24 UTC) (%) | Day 3 (00-24 UTC) (%) | Day 4 (00-24 UTC) (%) |
|---|---|---|---|---|---|---|
| **Active** | **≥ S1** | Yes | 100 | 70 | 50 | 20 |
| **Very Active** | **≥ S3 *** | No | 5 | 5 | 2 | 1 |
| * S3 ≥ 10 MeV ≥ 1000 pfu and / or ≥ 50 MeV ≥ 10 pfu. (pfu = $cm^{-2}sr^{-1}s^{-1}$) | | | | | | |

**Figure 4: Proton flux at GOES16, showing a steady rise above the S1 threshold over the last 24 hours.**

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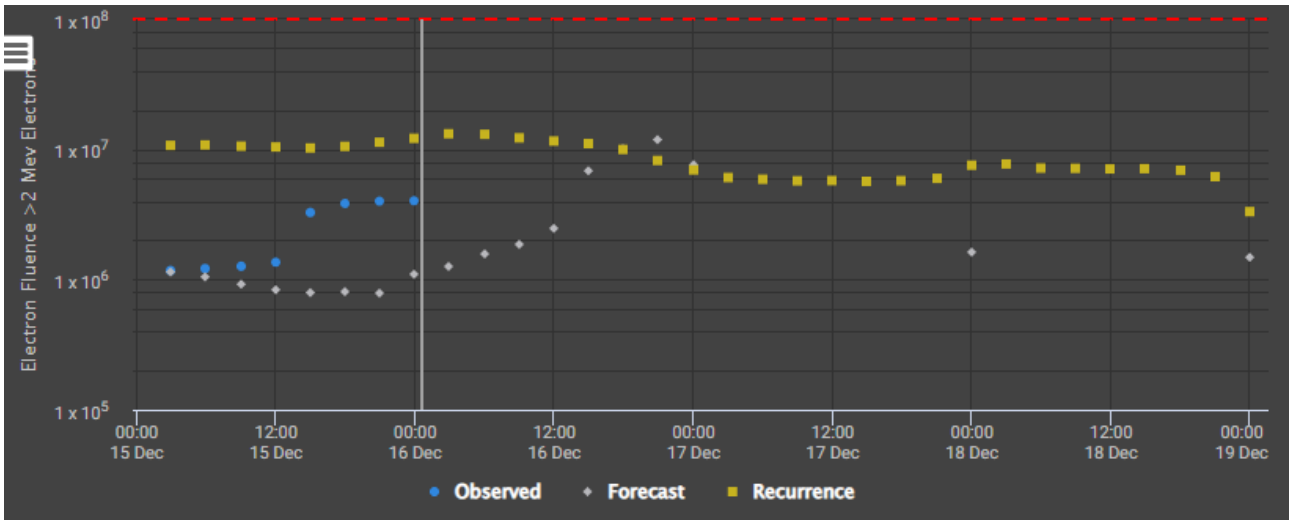
**High Energy Electrons Event (≥ 2MeV):**
High energy electron flux, as observed by GOES16, is currently at mostly background levels. Any current influence from CH79/+ is weak. Electron flux values at GEO are expected to remain fairly suppressed due to the likely arrival of two CMEs on Days 1-2 (16-17 Dec). As solar pressure from these features starts to ease, the observed flux may respond by increasing to moderate, perhaps peaking at high by Days 3-4 (18-19 Dec).

The associated 24-hour fluence is expected to remain below the Active threshold for much of the period, as indicated by REFM, although this model doesn't take account of CME impacts. Fluence may start to rise as the CME effects wane, with a chance of Active fluence by the end of Day 4.

| GEO Electron Environment<br>Probability (Exceedance) | Level ($cm^{-2}\ sr^{-1}\ day^{-1}$) | Past 24 Hours (Yes/No) | Day 1 (00-24 UTC)<br>(%) | Day 2 (00-24 UTC)<br>(%) | Day 3 (00-24 UTC)<br>(%) | Day 4 (00-24 UTC)<br>(%) |
|---|---|---|---|---|---|---|
| **Active** | **≥ 2 MeV ≥ $1x10^8$** | No | 1 | 1 | 10 | 30 |
| **Very Active** | **≥ 2 MeV ≥ $1x10^9$** | No | 1 | 1 | 1 | 1 |

**Figure 5: MOSWOC REFM showing a below Active forecast through the next 3 days. A rise is more likely on Day 4 (19 Dec).**

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